Melt Pool Imaging using an In-situ Near Infrared Imaging System

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Outline

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  - Melt Pool Imaging on Ti-6Al-4V Plate
  - Comparison to Optical Microscopy
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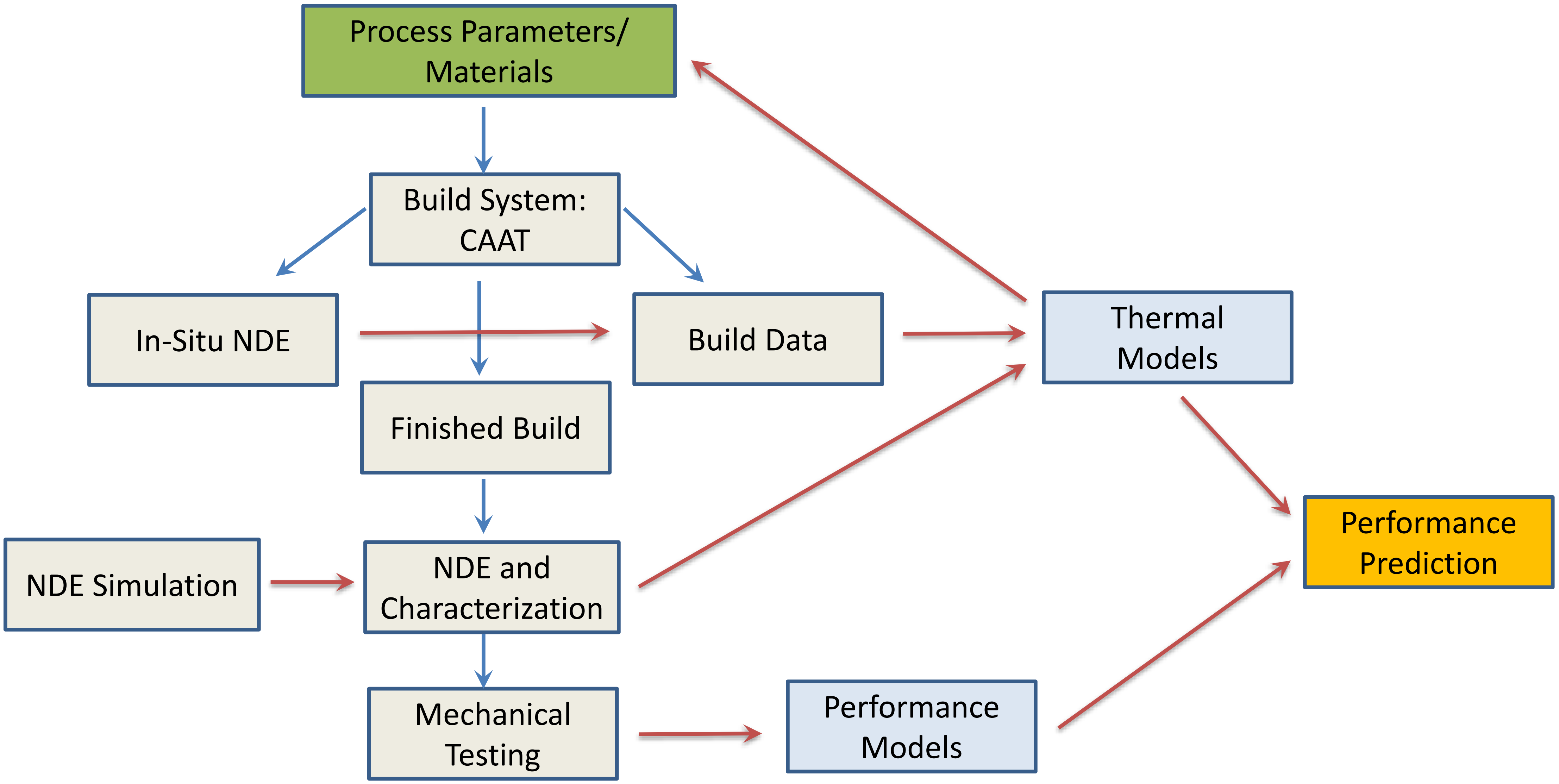
- Future Work

NASA Transformational Tools and Technologies Project – Additive Manufacturing (Metals)



Introduction

Objectives

• Investigate the use of a low cost in-situ near infrared (NIR) sensor for real time measurement of the thermal history for improved additive manufactured builds.

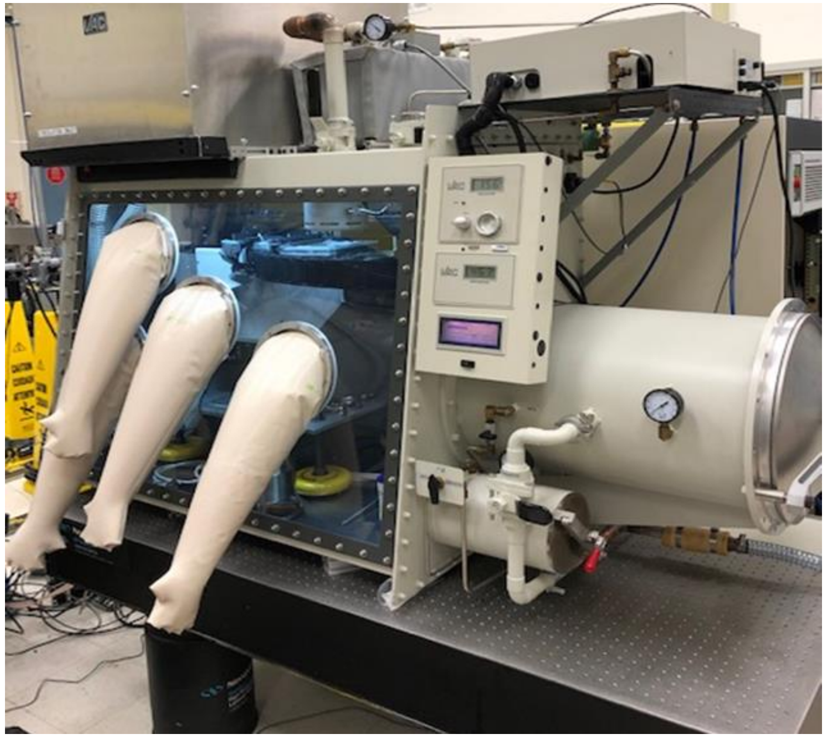
• Calibrate the NIR sensor and investigate the measured melt pool size based on varying process parameters.

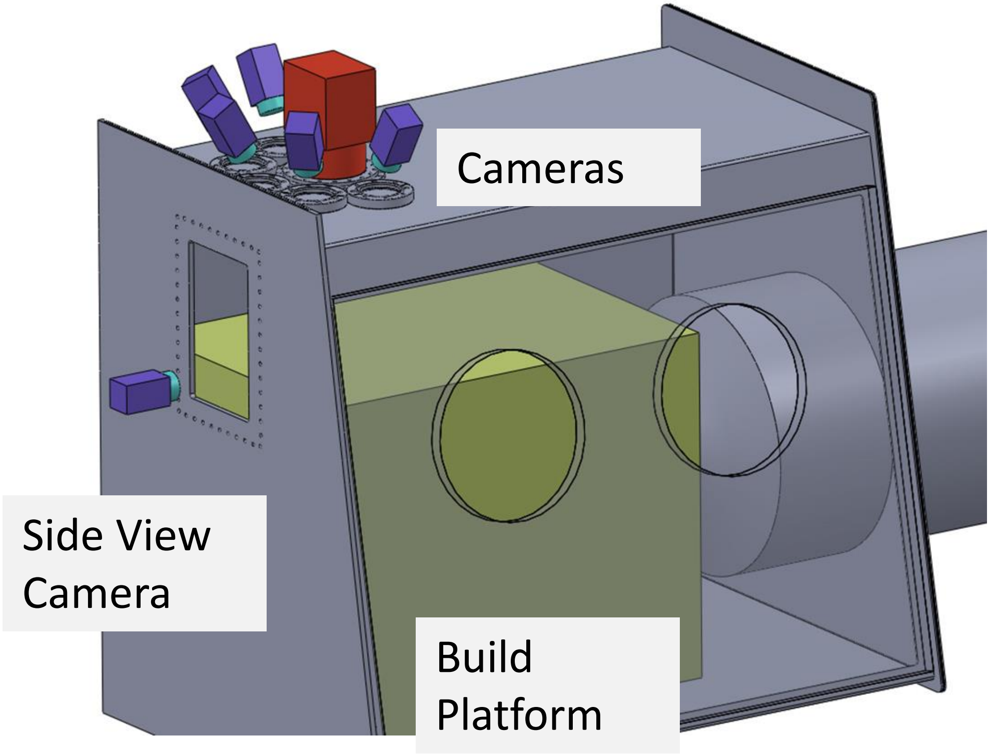
• Compare the melt pool width with microscopy measurements.

Payoffs

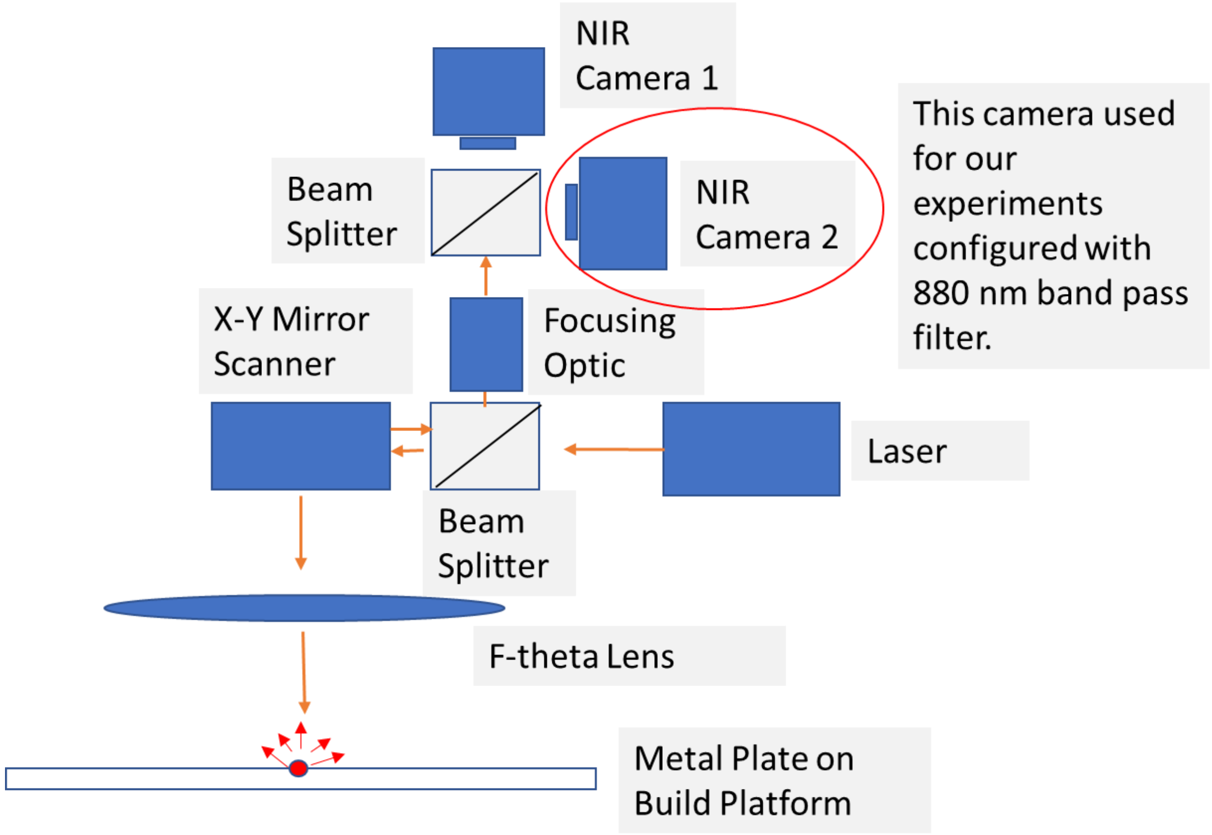
• Additively manufactured parts must be certified for broad application onto aircraft structures. By documenting the thermal history, process parameters for microstructure can be evaluated and real time inspections can be performed during the AM build. These results can be used to validate thermal models and process parameters.

Configurable Architecture Additive Testbed (CAAT)

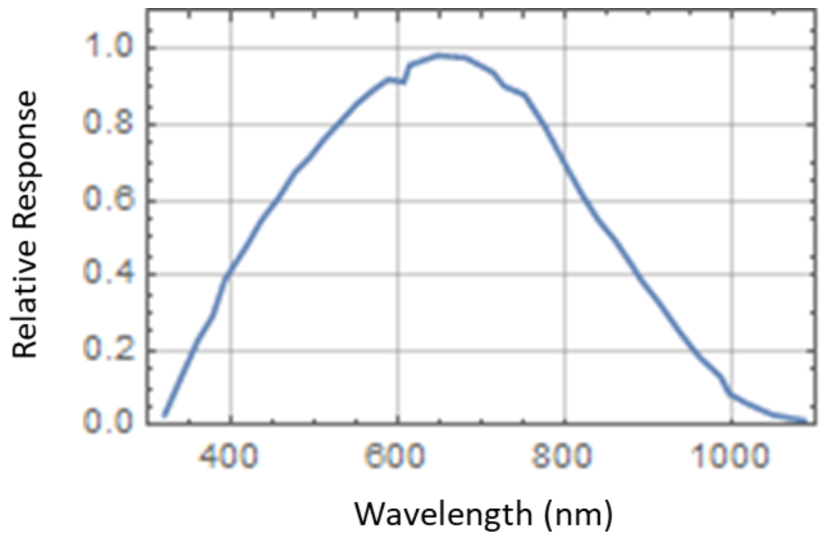




Co-axial NIR Optical Path



Basler acA640-750um

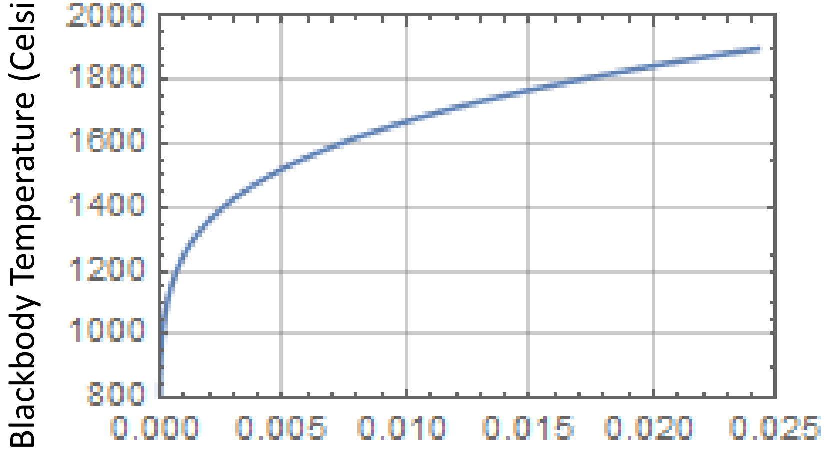


- NIR camera has 640 x 480 FPA, maximum frame rate = 751 Hz, pixel pitch is 4.8 x 4.8 um, configured with focusing optics and 880 nm narrow bandpass filter (875-884nm), resolution approximately 8.55 microns, ROI for images 144 x144, and provides frame rate of approximately 2,000 Hz.

Effective Radiance

$$Radiance = \int_{\lambda_1}^{\lambda_2} \frac{c_1}{\lambda^5 \left(e^{\frac{c_2}{(\lambda\,(T+273.15))}} - 1\right)} * \ sensor(\lambda) * filter(\lambda) * d\lambda \quad \text{where } c_1 = 2 * h * \ c^2 \quad \text{and} \quad c_2 = \frac{h * c}{k}$$

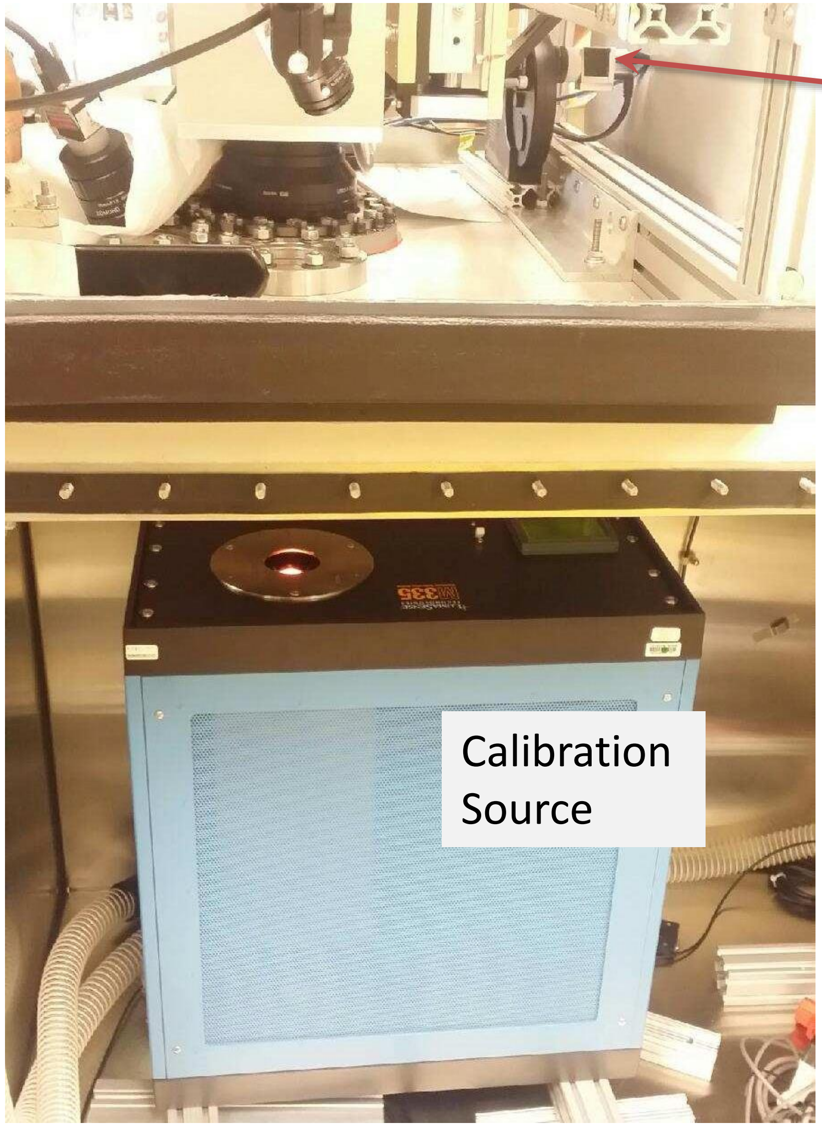
In-Band Effective Radiance Response



Effective Radiance (Watts/cm^2 - sr)

- Spectral band 875 to 884 nm defined by the 880 nm narrow bandpass filter.

Calibration of NIR Camera



NIR Camera

Basler acA640-750um

- Blackbody radiation source placed within build chamber for direct view.
- Temperatures used were 900, 1000, 1100, 1200, 1300, 1400, and 1500 degrees C.
- Integration times were varied 59, 75, 100, 150, 300, 500, 700, 900, 1200, and 1500 micro-seconds.
- Camera gain was set to 0 db.
- NIR camera was configured with 880 nm band pass filter.
- Camera frame rate approximately 2,000. Hertz with ROI pixel array size of 144x144.

NIR Camera Calibration Results from Blackbody Radiation Source

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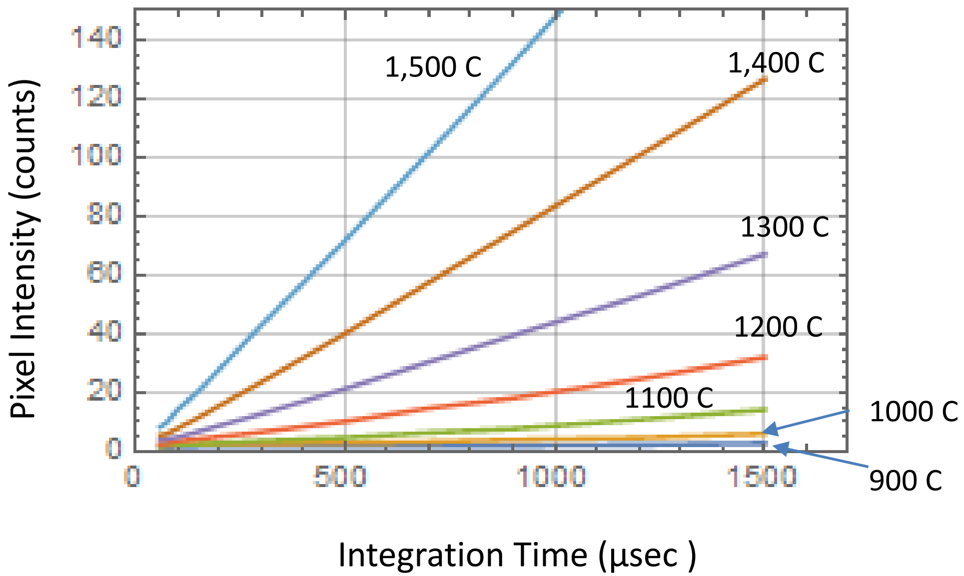
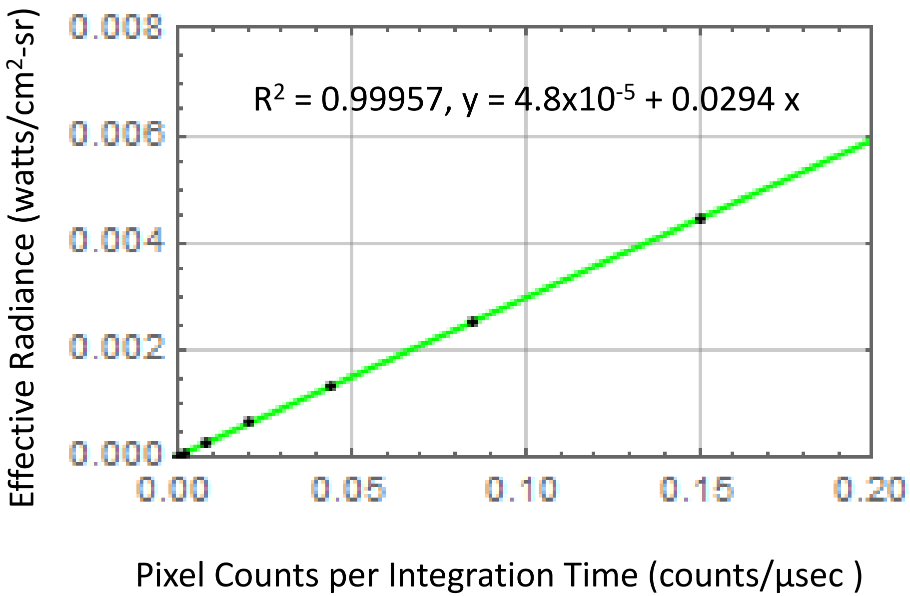
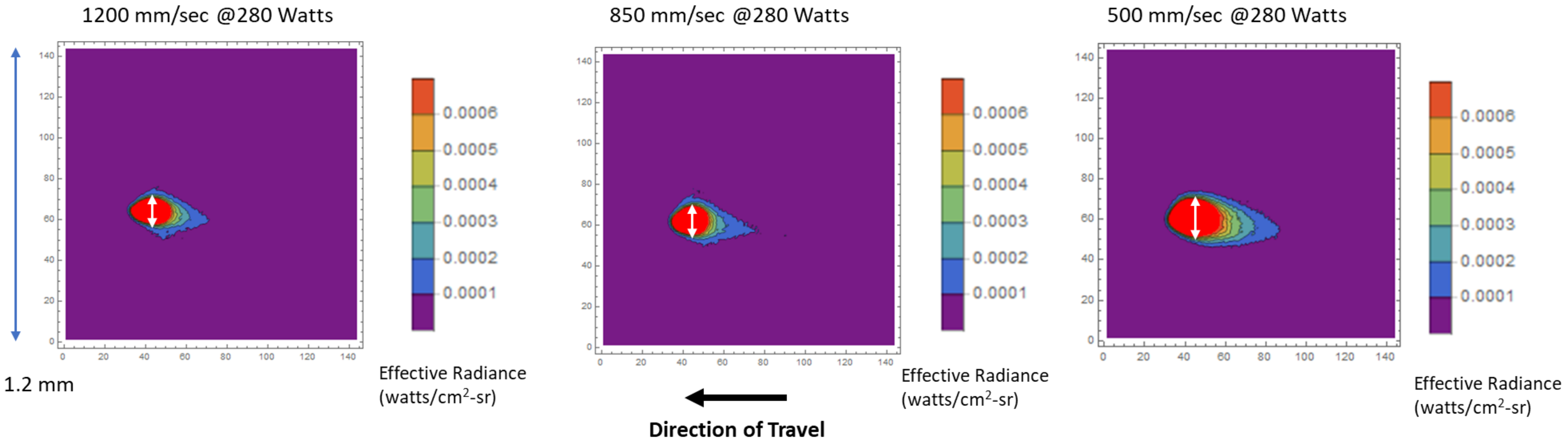
NIR Camera Response



Calibration Equation from Fit



In-situ NIR Melt Pool Imaging Results



Requirements for Measurement of Melt Pool Width

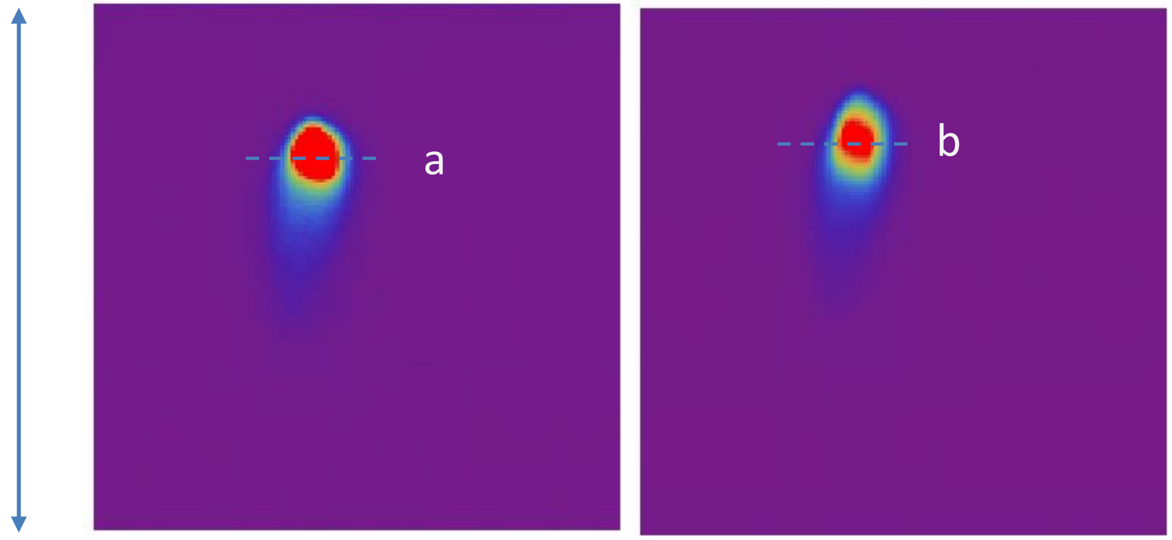
- Thermal camera pixel resolution – Measured Pixel Resolution Approximately 8.55 microns.
- Solidus temperature value – 1610 Degrees C (Ti-6Al-4V).
- Blurring due to movement of laser beam vs. camera integration time and frame rate.
- Surface emissivity value (vary with material, surface geometry and temperature).
- Accurate destructive measurements using microscopy.

Removal of Blurring using Inverse Filtering

- Laser velocity of 500mm/sec combined with camera integration time (200 microseconds) results in ~ 12 pixel blur.
- Use Weiner inverse filtering technique to remove camera blur.

$$W(u,v) = \frac{H^{*}(u,v)}{|H(u,v)|^2 + K(u,v)}$$

$$Deblurred\ Image\ (u,v) = W(u,v) BlurredImage\ (u,v)$$

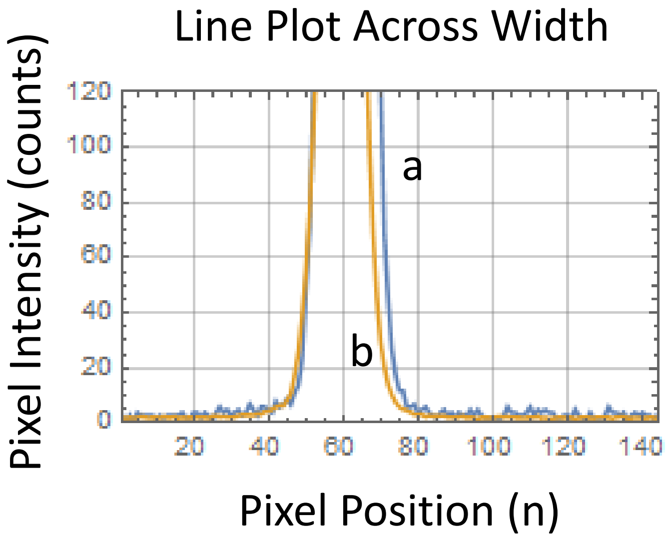


1.2 mm

Original Image 500mm/sec

<u>Deblurred Image</u> using 12 pixel correction Wiener filter

Intensity Counts



Melt Pool Imagery for Various Emissivity Values Compared to Optical Microscopy – Blurring Uncorrected

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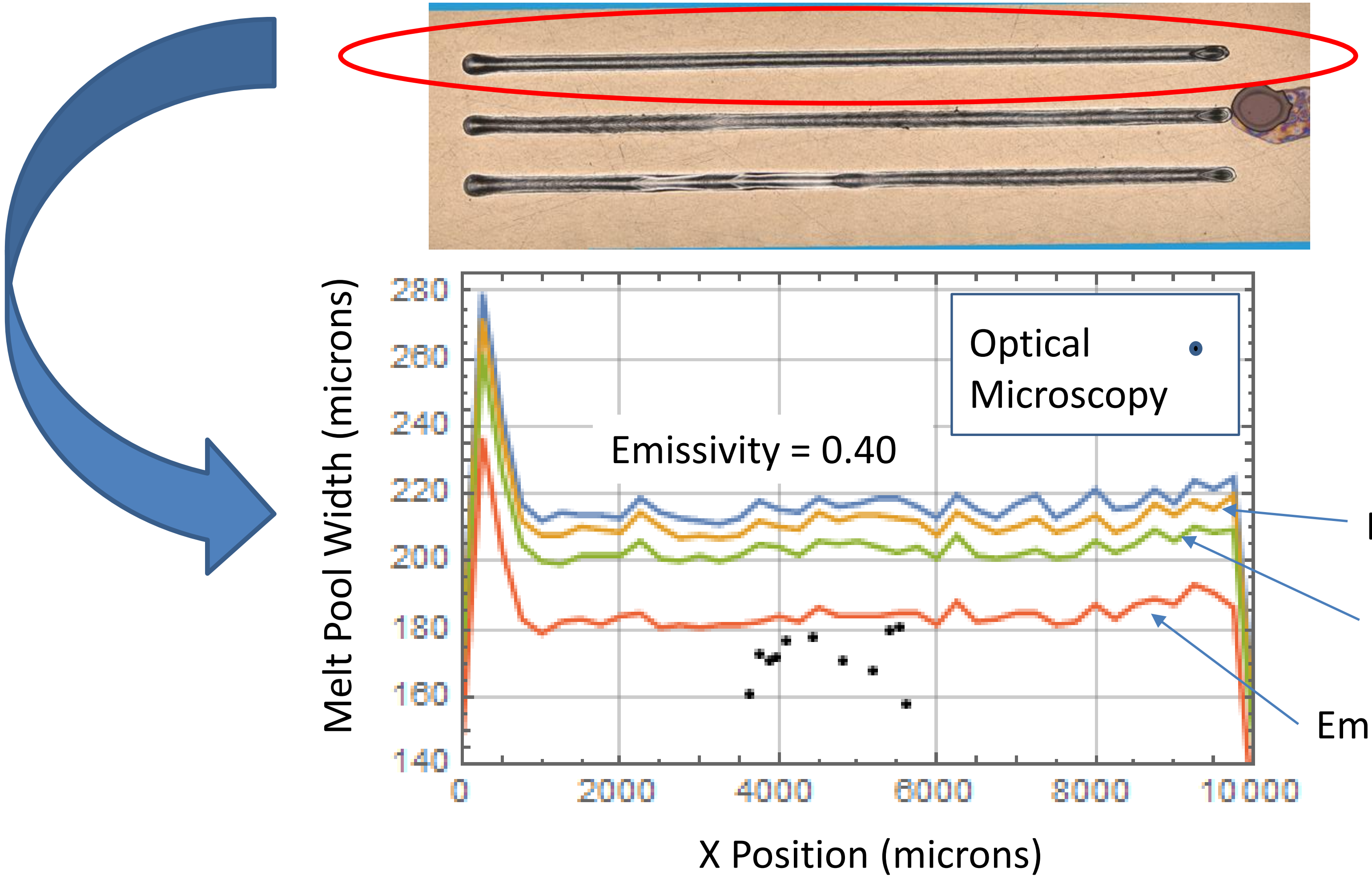
Top Down Image



Laser Scanning Direction →

Melt Pool Imagery for Various Emissivity Values Compared to Optical Microscopy – Blurring Corrected

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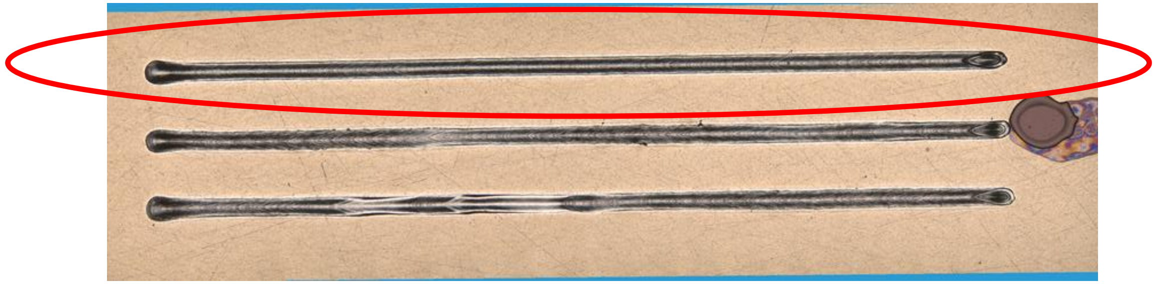
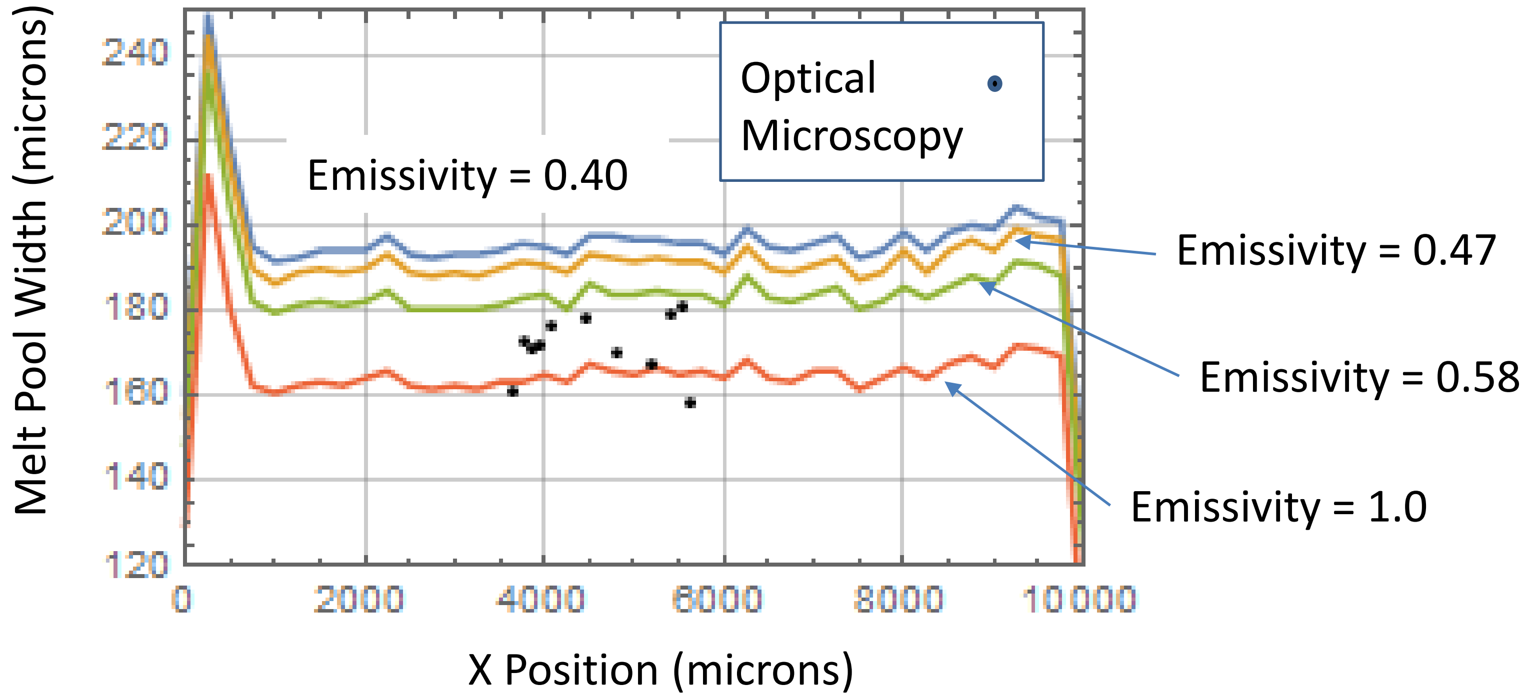
Top Down Image



Laser Scanning Direction



Optical Microscopy Measurement Challenges for Melt Pool Width

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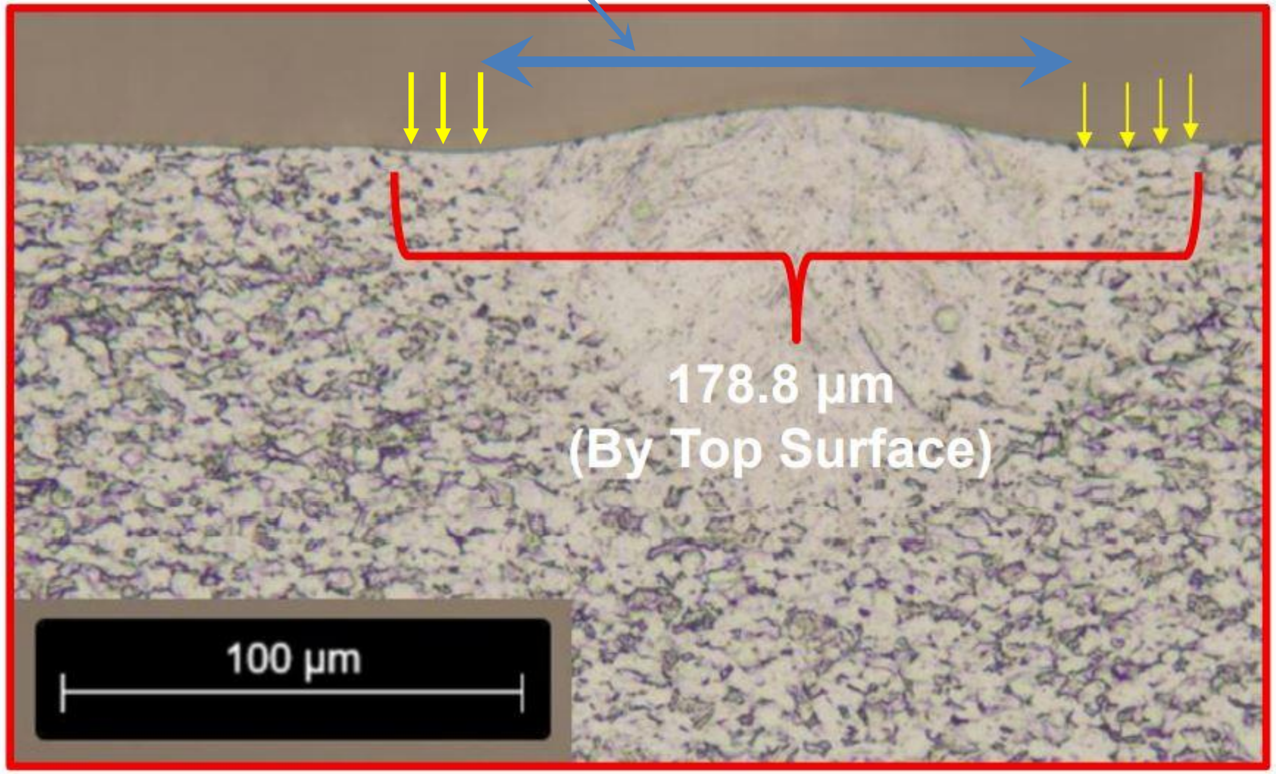
Melt Pool Width
by Cross Section



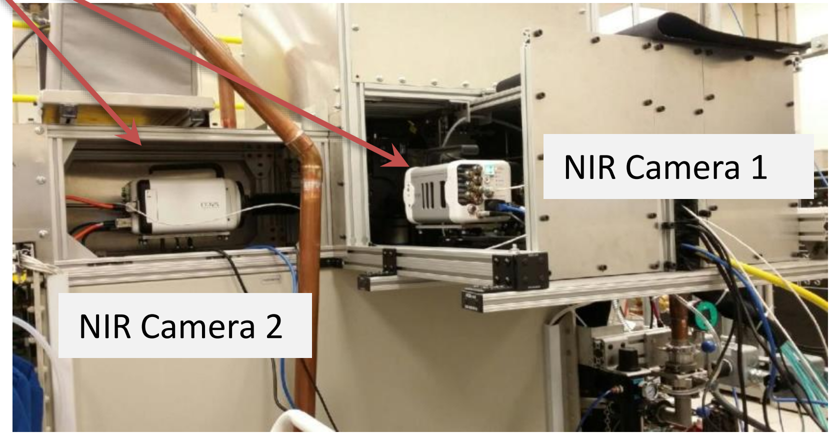
Conclusions

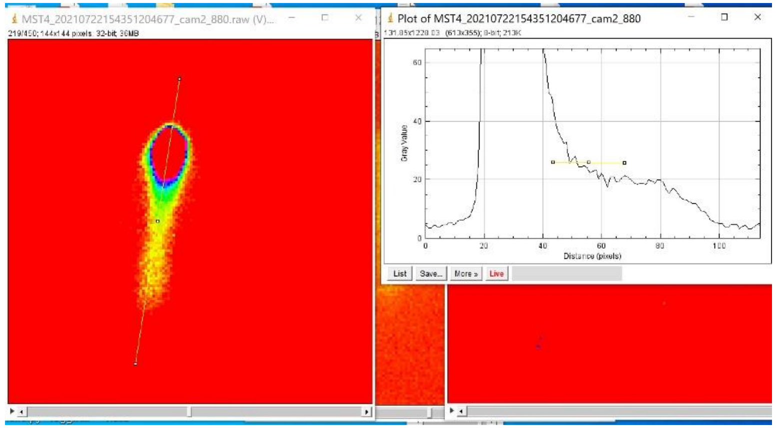
- A low cost NIR camera was calibrated and used to measure the width of the melt pool on a Ti-6Al-4V plate.
- Inverse filtering technique used to remove image blurring and emissivity was varied to obtain a measurement of melt pool width.
- Optical microscopy measurements were used to compare the NIR melt pool width with marginal agreement.
- Comparison of melt pool width measurements to FEM models for given process parameters has begun.

Future Efforts

- Higher speed cameras will be used for improved temporal and spatial imaging.
- Investigate pyrometry imaging techniques for confident thermal measurements.
- Incorporate real time NDE during build using thermal transient after solidification US Patent # US11027332B2 issued 6/08/21 “System and Method for In-Situ Characterization and Inspection of Additive Manufacturing Deposits Using Transient Infrared Technology”.

Photron Nova S6





Melt Pool Image of Ti6-4 from CAAT